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Modification of landscape as promoter of change in structure and taxonomic diversity of reptile´s communities: an example in tropical landscape in the central region of Mexico

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Abstract

The degree of species loss was assessed by comparing the structure of communities and species diversity of reptiles from three different environments, one natural (tropical evergreen forest [TEF]) and two modified (shaded coffee plantation [SCP] and grazing area [GA]) from the mid portion of the Sierra Madre Oriental, Mexico. The results showed 29 species, 18 in TEF, 13 in SCP and 12 in GA. According to the abundance of each species, the reptile structure for TEF and SCP was similar and they both differed from GA, while the diversity (effective number of species) was the highest for TEF. The percentage of number of species from TEF accounted for 28% more species than SCP and GA, which indicated a species loss of about 70% in disturbed environments. The values of beta diversity were the highest between TEF and GA, followed by SCP and GA and to a lesser degree between TEF and SCP, which indicates that TEF showed a high number of exclusive species. Our results suggest that carrying out long-term studies that include richness and diversity in environments with different levels of disturbance, in addition to including characteristics of natural history, might enhance the development of more efficient conservation strategies for these species.

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Keywords
Alpha diversity, beta diversity, conservation, disturbed environments, taxonomic diversity

Introduction

The development of agriculture and livestock activities has generated a high loss of original vegetation in diverse ecosystems of the world (Cayuela et al. 2006, Barragán et al. 2011). The tropical environments have been the most threatened, notably reducing their territorial extension (Sodhi et al. 2010) and diminishing the biodiversity of these environments (Kurz et al. 2014, Zhang et al. 2014). Amongst the main causes in the loss of territorial extension and, therefore, its biodiversity, are those caused by the anthropogenic effect, such as the change of land use or fragmentation of the landscape (Vié et al. 2009).

In tropical environments, the decline has been documented for many biological groups, such as arthropods (Benítez-Malvido et al. 2016), amphibians (Pineda et al. 2005, Pineda and Halffter 2004, Cruz-Elizalde et al. 2016), mammals (Garmendia et al. 2013), birds (Sekercioglu et al. 2004) and reptiles (Gibbons et al. 2000, Berriozabal-Islas et al. 2017). Additionally, it has been noted that modified environments negatively affect ecological interactions, as well as in survival rates, population growth, gene flow amongst populations and behaviour of individuals (Jones 1981, Dixo et al. 2009).

Changes in landscape structure influence the conformation of biological communities amongst sites (Pereyra et al. 2018), modifying their structure and the relative abundances of the species. An example of this, is the group of reptiles, which, due to their ecological and physiological characteristics, limited home ranges or the low vagility of their species, are highly sensitive to changes in the environment where they occur (Kurz et al. 2014, Berriozabal-Islas et al. 2017). Despite some studies registering that the richness of reptile species decreases as natural environments are transformed into cultivated areas or urbanised environments (Faria et al. 2007, Gardner et al. 2007), several other studies show that the surrounding matrix can maintain a richness similar to the fragments of original vegetation (Urbina-Cardona et al. 2006). For example, Suazo-Ortuño et al. (2008) found that lizards showed a high preference for disturbed areas (farming and grazing areas). These authors reported a steady increase in population size for two consecutive years of sampling and their conclusion was that anthropogenic disturbance in some circumstances might be a positive factor for some species and negative for others.

In Mexico, tropical forest remnants and transformed environments, such as agricultural and grazing areas make up the current landscape of some biogeographic regions (Hernández-Ruedas et al. 2014). An example of these is the Sierra Madre Oriental located in central Mexico, which is one of the provinces with most species richness and endemism for diverse biological groups such as amphibians, reptiles, plants, mammals and birds (Canseco-Márquez et al. 2004). However, most of area of this province

has been strongly affected by human disturbance (Castro-Navarro et al. 2017). Based on the previous theoretical context and on the landscape change affecting the composition of biological communities through time and for multiple ecological relationships, many reptile species associated with the native vegetation are usually very sensitive to habitat disturbance (Berriozabal-Islas et al. 2017). Subsequently, it makes them useful as indicators of environmental health; for example, richness and relative abundance of species are good indicators for the status of an ecosystem (Semlitsch and Bodie 2003). Therefore and considering that reptiles are bioindicator groups of habitat disturbance (Suazo-Ortuño et al. 2008), in this study, we expected to find a pattern of change in community composition amongst environments, particularly species loss due to the transformation of their environment, change in relative abundance of species by the environment, high values of beta diversity as well as low taxonomic diversity in transformed environments.

We anticipated a high richness and species diversity in a native environment (tropical evergreen forest), compared to two transformed environments (shaded coffee plantation and grazing areas). In addition, we predict a loss of species from native evergreen forest to transformed environments due to turnover of species (i.e. changes in species composition amongst local assemblages, Dobrovolski et al. 2012). This study can serve as the basis for developing conservation strategies for this and other biological groups that inhabit transformed environments.

Methods

Study area

The study area is located in the central region of Sierra Madre Oriental and within the Natural Protected Area called Corredor Ecológico Sierra Madre Oriental (INEGI 2009, CONANP 2016). This area is composed of tropical forest and patches of cloud forest, being important for the species richness and their endemism. The zone is located in the eastern portion of the state of Hidalgo. Elevations range from 110 to 1700 m a. s. l; mean annual temperature is 23.7 °C and annual precipitation is 2558 mm (INEGI 2009).

Analysed environments

Surveys were carried out in tropical evergreen forest (TEF), shaded coffee plantation (SCP) and grazing area (GA) and they were identified according to the vegetation structure as described by Rzedowski (2006; Figure 1).

Tropical evergreen forest (TEF): This vegetation type shows ca. 25% of the deciduous plant species, with tree height between 20 and 30 m, with multilayer vegetation, rich in lianas and epiphytes. The herbaceous layer is composed of the species *Campelia zononia*,

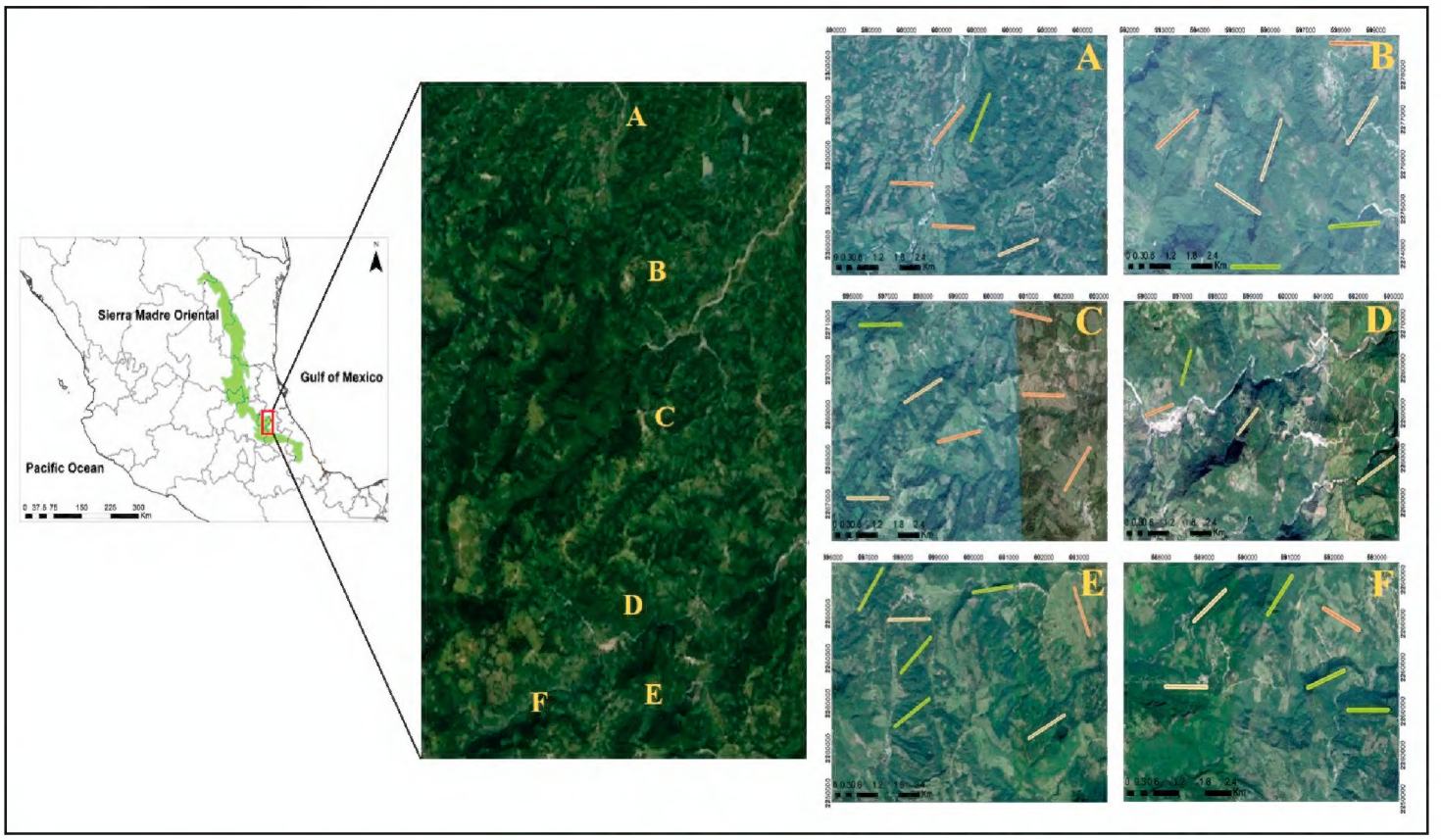

Figure 1. Location of the study area, the transects in green representing the remnants of tropical evergreen forest. Transects in brown colour show shaded coffee plantation and red transects represent grazing areas.

Fuirena simplex, *Peperomia obtusifolia* and *Zebrina pendula*; while the main arboreal species are *Cedrela odorata*, *Bursera simaruba*, *Carpodiptera ameliae*, *Persea schiedeana*, *Cecropia obtusifolia*, *Heliocarpus appendiculatus*, *Dendropanax arboreus*, *Trema micrantha* and *Jaegeria macrocephala*, amongst others (Puig 1991).

Shade coffee plantation (SCP): The SCP represents an important area of the landscape of the region (Salazar Ortiz et al. 2013). This kind of environment contributes to water retention and maintains the temperature and humidity in a manner which is not highly variable and together provides similar microhabitats to the natural forest that is used by different reptile species. Within the area of SCP, there are diverse woody plant species, such as *Alchornea latifolia*, *B. simaruba*, *C. odorata* and *Ceiba pentandra* (Salazar Ortiz et al. 2013).

Grazing area (GA): In the region, various government programmes have been developed to drive the expansion and utilisation of the grazing areas. Therefore, large areas of land of TEF have been transformed into grazing areas, which has resulted in a homogeneous environment, where the dominant grasses are *Paspalum* sp and *Andropogon* sp. (Callejas Chávez et al. 2008) and secondary vegetation formed by heliofila flora having a group succession going by herbaceous, shrubs and tree. The margins of the grazing areas are invaded by the herbaceous *Achyrates repens*, *Helenium mexicanum* and *Salvia coccinea*, while *Abutilon notolophium*, *Hamelia patens* and *Piper hispidum* are the dominant shrubs. Also, trees of the species *Acrocomia mexicana*, *Bursera simaruba*, *Parmentiera edulis*, *Ceiba pentandra* and *Tabebuia pentaphylla* together provide ecological conditions in these kinds of places (Puig 1991).

Sampling design

The fieldwork was carried out from February 2010 to January 2011, in which 12 sampling events were carried out, each with three days of surveys (one day per environment), therefore, there were 36 samplings for each environment. Due to different amounts of areas of TEF, SCP and GA, the region was subdivided into six areas of 32 km^2 each (Figure 1). Samplings were made in three different transects with a length of 1000 m × 20 m wide and each environment, independent of subdivisions, was sampled 12 times. Transects were separated by a distance of 2.5 km from each other and 12 km between areas of sampling. In each environment, three kinds of surveys were made during each visit (with three transects each), diurnal (from 09:00 h to 13:00 h), sunset (15:00 h to 19:00 h) and nocturnal (21:00 h to 01:00 h). For each environment, we invested a sampling effort of 36 person-hours (12 h × 3 persons = 36 per day), which made a total sampling effort of 1296 h for the entire study (432 person-hours per environment; Cruz-Elizalde et al. 2015).

Sampling was conducted by using direct searches for individuals in different numbers of transects per environment. Individuals were sought in different microhabitat types and habits, such as terrestrial (rocks, holes, logs), aquatic (amongst aquatic vegetation, water bodies) and arboreal (trunks, branches). The sampling period was based on the activity of the species groups. For example, lizards of the genus *Anolis* and *Ctenosaura* are diurnal and their activities peak from 0900 h to 1300 h, while *Hemidactylus*, *Lepidophyma* and the snakes *Thamnophis* and *Leptodeira* have sunset and nocturnal activity approximately from 1900 h to 2200 h (Hernández-Salinas and Ramírez-Bautista 2012).

Recorded specimens were identified in the field using dichotomous keys and released at the same place and the total number of specimens for each species was reported (Moreno 2001, Hernández-Salinas and Ramírez-Bautista 2012). The scientific names were updated following the most recent literature on the study group (Wilson et al. 2013, Meza-Lázaro and Nieto-Montes de Oca 2015).

Completeness analysis

To assess the completeness of the inventory for each environment, species accumulation curves were performed (Moreno 2001) using Bootstrap estimator, which has been considered as one of the most accurate methods to assess reptile communities more precisely, because it better highlights rare species and less so dominant species (Carvajal-Cogollo and Urbina-Cardona 2008). Likewise, algorithms that evaluate the species represented by one (singletons) or two (doubletons) individuals in the sampling were estimated (Colwell and Coddington 1994). These estimators assume that, as the sampling number increases and the curves intersect, the inventories are close to completion (Jiménez-Valverde and Hortal 2003). Species accumulation curves were performed using the programme ESTIMATES ver. 750 (Colwell and Coddington 1994).

Structure and species diversity

Rank-abundance curves were performed to assess structure and composition of the species in each community and the dominant and/or rare species for each environment were identified (Magurran 1998). On the other hand, the diversity for each community was determined with the Shannon-Wiener index using the effective number of species (Jost et al. 2010). The true diversity value was expressed as $^{1}D = \exp(H')$, where ^{1}D is the value of true diversity for each community and exp (H′) is the exponential of the Shannon index (Jost 2006, Jost et al. 2010).

Results obtained from the true diversity analysis allowed the comparison of how distant the diversity is amongst communities, as well as the degree of magnitude (percentage) that distinguishes them from each other. To extract the percentage of diversity between communities we used the formula $(D_B x100)/D_A$ where D_A is the value of diversity of community A, and D_B is the value of diversity of community B (Moreno et al. 2011).

Taxonomic diversity

To assess the taxonomic diversity for each community of the environments, the taxonomic distinction of Warwick and Clarke (1995, 2001) was used, which calculates the mean (Delta = Δ^+) and the variance (Lambda = Λ^+; sensu Clarke and Warwick 1998) of the taxonomic diversity of the reptiles from each environment. This method is based on the assumption that one community with high phylogenetic relationships amongst its species will be less diverse (phylogenetically) than a community with low phylogenetic relationships amongst its species (Warwick and Clarke 1995, Clarke and Warwick 1998, Moreno et al. 2009). The formula is represented as: $\Delta^+ = [2\Sigma\Sigma_{i<j}\ \omega_{ij}]/[S\ (S\text{-}1)]$ and $\Lambda^+ = [2\Sigma\Sigma_{i<j}\ (\omega_{ij}\text{-}\Delta^+)^2]/[S\ (S\text{-}1)]$, where ω_{ij} is the taxonomic distance between each species pair j and i and S is the number of observed species in the sampling (Warwick and Clarke 1995). A high value of Δ^+ reflects a low relationship amongst species and, therefore, it is represented as a measure of taxonomic diversity. However, Λ^+ is not a measure of equity in the structure of the taxonomic diversity, thus a high value of Λ^+ indicates an under- or over- representation of the taxa in the sampling (environments).

To detect differences in the taxonomic diversity for each environment, the samples were compared (species list per environment) and the regional species pool generated a null model with 1000 re-samplings (Clarke and Warwick 1998). In this model, the average and variance of the sample numbers were used and species plotted with a confidence interval of 95% (Clarke and Warwick 1998). To assess taxonomic diversity, we used the classification by Wilson et al. (2013), which includes five taxonomic categories: species, genus, family, order and class. The analysis was developed with the PRIMER 5 programme (Clarke and Gorley 2001).

Beta diversity (β)

Finally, to determine the values of change in species composition amongst environments, we used the formula β = 1-J (Chao et al. 2005). In this formula, J represents the values of the Jaccard similarity index that takes the values of 1 when both communities show the same species composition and 0 when the species in the communities are entirely different (Moreno 2001). This analysis was performed with PAST (Hammer et al. 2001).

Results

Species richness

In this study, 29 species of reptiles were recorded, included in 15 families and 27 genera, with the group of snakes best represented by 19 species (Table 1). Species composition was in the following order: TEF with 18 species, SCP with 13 species and GA with 12 species.

According to the species accumulation curves for each environment, in the TEF environment (Figure 2a), an asymptotic phase is shown, which indicates that the species inventory in TEF is close to being complete (95% of completeness), missing approximately only two or three species. In the SCP (Figure 2b), the same estimator showed that the species accumulation curve has not yet reached an asymptotic phase (90%); this result indicates that around four and five species remained to be recorded in this environment, even though the singletons and doubletons are crossed (Figure 2b). Finally, for GA, the estimator showed that the species inventory is complete (100%), which is consistent with the crossing of the singletons and doubletons in the species accumulation curve (Figure 2c).

Structure, composition and diversity

The abundance-rank curves showed a change in the structure of the communities inhabiting a modified environment. Structure and equity of reptile communities were similar in TEF and SCP, but distinct from GA (Figure 3). Abundance-rank curves for TEF and SCP showed that lizard species such as *Holcosus amphigrammus* and *Sceloporus variabilis* were the most dominant, while, for the GA environment, the species were *Hemidactylus frenatus* and *S. variabilis* (Figure 3). In contrast, uncommon or rare species for TEF were *Atropoides nummifer* and *Tantilla rubra*, while, for the SCP environment, *Bothrops asper* and *Micrurus diastema* were uncommon or rare. Finally, in the GA environment, *Mastigodryas melanolomus* and *Thamnophis proximus* were the rarest species (Figures 3 and 4).

On the other hand, TEF exhibited the highest value of diversity in the effective number of species with D^1 = 14.1, which is equivalent to the environment with greatest

Table 1. Species list and abundance of reptiles recorded during the fieldwork and in each analysed environment. TEF = tropical evergreen forest, SCP = shade coffee plantation and GA = grazing areas.

Family	Species	Acronym of species	Abundance		
			TEF	SCP	GA
Kinosternidae	*Kinosternon herrerai*	Z			8
Corytophanidae	*Basiliscus vittatus*	Ñ	2		
Dactyloidae	*Anolis naufragus*	C	8	6	
Gekkonidae	*Hemidactylus frenatus*	V			22
Iguanidae	*Ctenosaura acanthura*	Y			10
Phrynosomatidae	*Sceloporus variabilis*	B	12	8	29
Sphenomorphidae	*Scincella gemmingeri*	D	6	4	
	Scincella silvicola	H	4	5	
Teiidae	*Holcosus amphigrammus*	A	20	13	
Xantusiidae	*Lepidophyma sylvaticum*	L	3		
Boidae	*Boa imperator*	G	5		
Colubridae	*Drymarchon melanurus*	J	4	5	
	Drymobius margaritiferus	T		6	9
	Lampropeltis polyzona	I	4		
	Leptophis diplotropis	O	2	2	
	Mastigodryas melanolomus	C′			3
	Spilotes pullatus	M	3		
	Tantilla rubra	Q	2		
Dipsadidae	*Coniophanes fissidens*	E	5	2	
	Coniophanes imperialis	A′			6
	Leptodeira maculata	W			22
	Ninia diademata	F	5		
	Tropidodipsas sartorii	X			15
Elapidae	*Micrurus diastema*	N	3	2	
Natricidae	*Nerodia rhombifer*	U		4	17
	Storeria dekayi	S		6	12
	Thamnophis proximus	B′			5
Viperidae	*Atropoides nummifer*	P	2		
	Bothrops asper	K	4	1	
Totals			**94**	**64**	**158**

species richness, followed by SCP with a value of D^1 = 10.2 and GA with a similar value to the latter with D^1 = 10.1 of effective species. In this section, it is important to point out that the observed equivalences in percentage terms indicated that TEF had 28% more species than SCP and GA.

Taxonomic diversity and beta diversity

The graphs of taxonomic diversity showed that TEF and SCP present similar mean values of taxonomic diversity (58.2 and 58.5, respectively, Delta+; Figure 5a), while GA

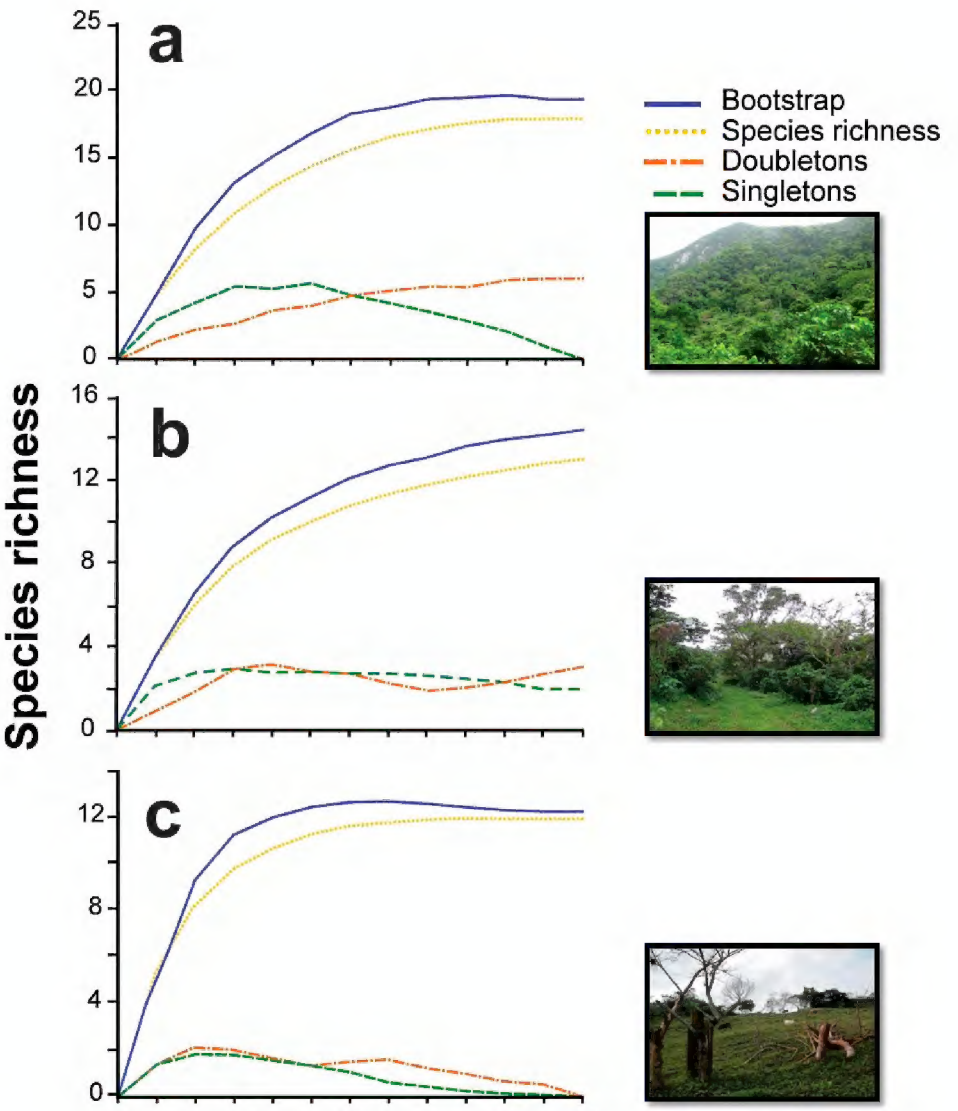

Figure 2. Species accumulation curves for **a** species of tropical evergreen forest **b** species of shaded coffee and **c** for grazing areas.

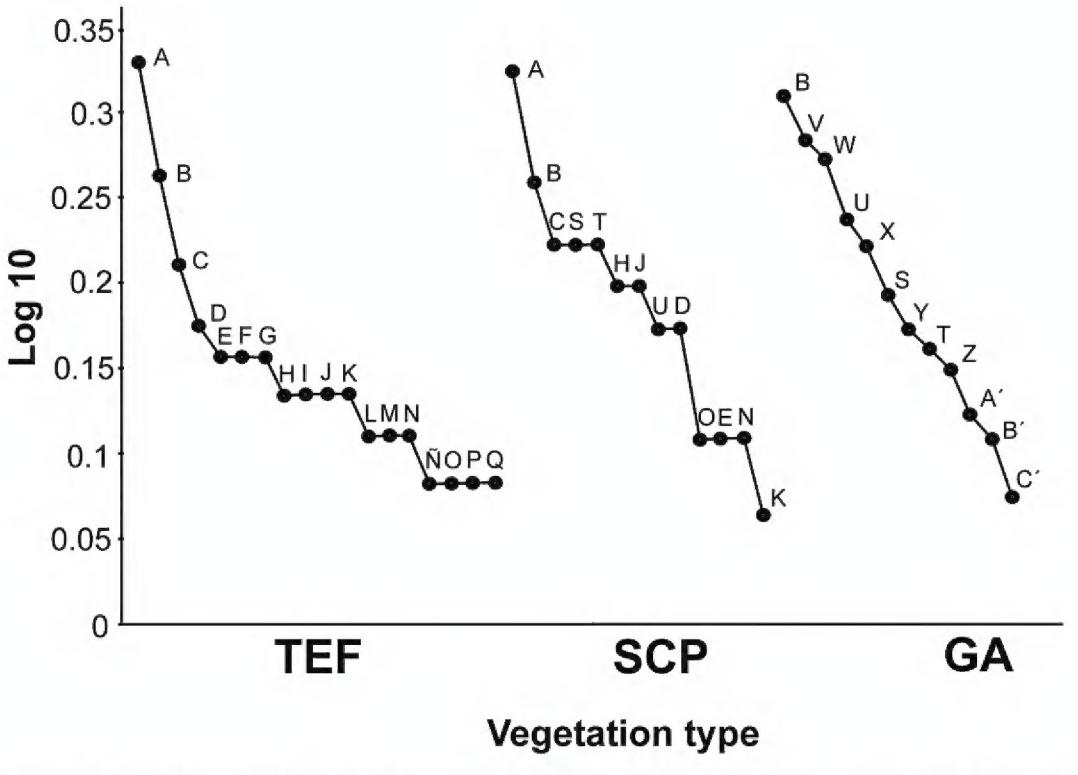

Figure 3. Curves of rank-abundance of reptiles where community composition is evaluated by type of environment. The species are represented by letters (see Table 1) in each curve (TEF = tropical evergreen forest, SCP = shaded coffee plantation and GA = grazing areas).

Figure 4. Reptile species that are under some risk category according to the NOM-059-2010 or whose distribution is restricted to the study region (see text). H= *Scincella silvicola*, L= *Lepidophyma sylvaticum*, Q= *Tantilla rubra*, P= *Atropoides nummifer*, Y= *Ctenosaura acanthura*, T= *Drymobius margaritiferus*, O= *Leptophis diplotropis*, N= *Micrurus diastema*, Z= *Kinosternon herrerai*, W= *Leptodeira maculata*, X= *Tropidodipsas sartorii* and B′= *Thamnophis proximus*.

showed higher values (61.2), despite having presented the lowest richness and effective number of species. The same pattern occurred in the variation of taxonomic diversity, where TEF and SCP showed similar values (38.5 and 38.7, respectively), while the greatest value for GA was 107.6 (Lambda+; Figure 5b). Finally, with respect to beta diversity, the values were elevated between TEF and GA with 0.97 and between SCP and GA with 0.81; the lowest value was between TEF and SCP with 0.52.

Discussion

The richness, diversity and composition of reptile species in the analysed environments were different from each other. The results showed a general pattern of species loss and change in structure communities from preserved forest remnants to areas of SCP and GA. This pattern could be driven by the loss of vegetation cover, as well as loss of water bodies and changes in humidity and temperature amongst places, which together provide appropriate conditions (e.g. ideal microhabitats) to be exploited by different species of reptiles (Gardner et al. 2007). Therefore, habitat transformation directly influences species richness and its abundance. Malcolm (1994) found similar results when he analysed the richness and species diversity from different biological groups in fragmented forests from Brazil. This pattern of change of species amongst environments has also been observed in other studies. For example, Philpott et al. (2008) found that there is a significant loss of ants, birds and trees in coffee systems. These authors have argued that the anthropogenic factors, such as construction of communication routes,

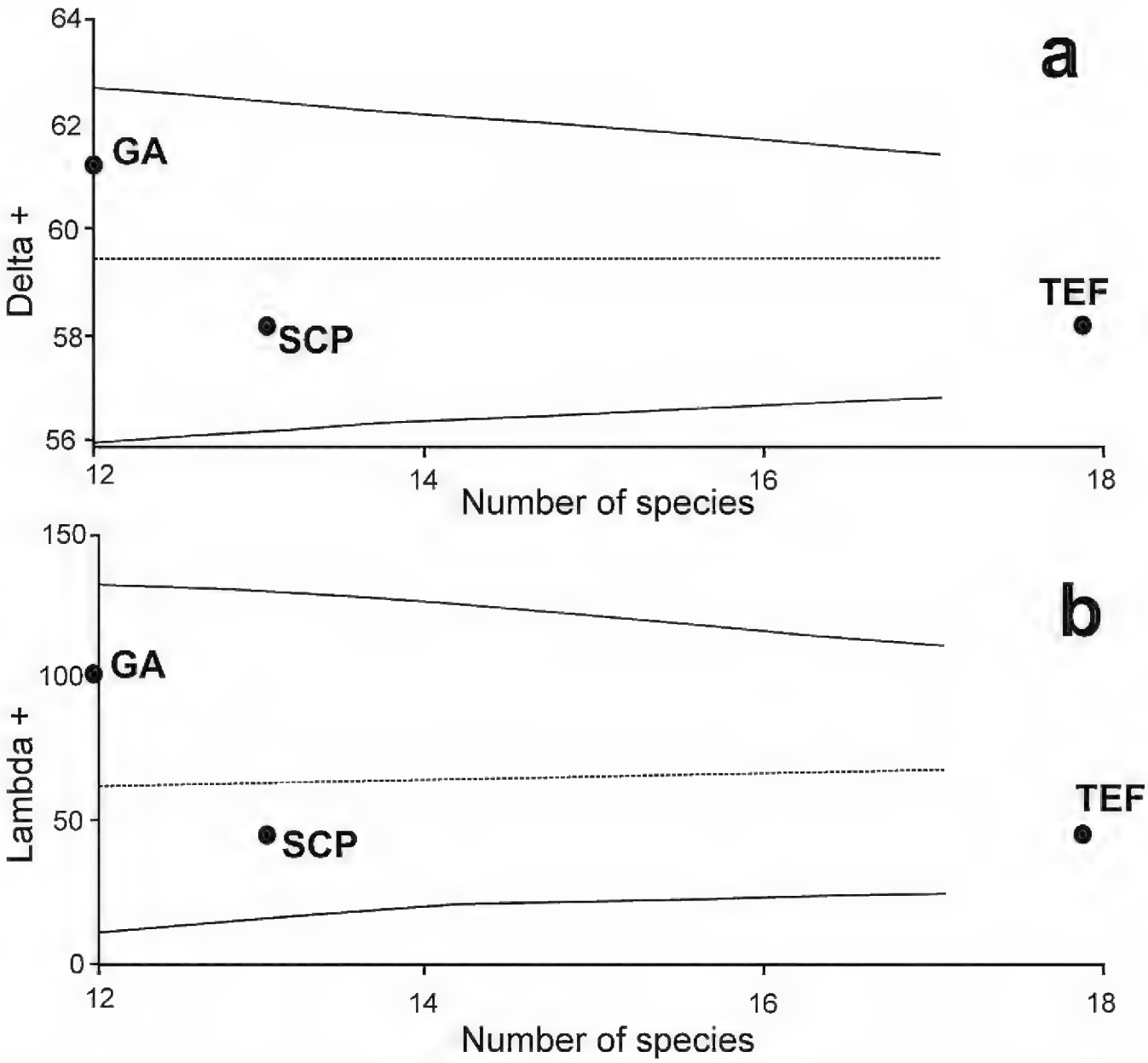

Figure 5. Average of taxonomic diversity (a; Delta+) and variation in taxonomic diversity (b; Lambda+) for the analysed environments (TEF, SCP and GA). Continuous lines represent confidence interval at 95% according to the null model.

home constructions and deforestation for grazing areas negatively affect reptile species distribution at the local level (Dornelas et al. 2011).

Analysis of completeness indicated that there are still species to record in SCP and TEF, while GA showed the highest percentage of completeness. This pattern might be caused by two factors, *i*) the method used in this study and *ii*) the complex structure pertaining to each environment. GA showed a low number of microhabitat types which could be occupied by reptile species, including rocky crevices, logs, hollows of trees or water bodies. While the opposite was observed in SCP and TEF, with both sites containing leaf litter, logs, bromeliads and undergrowth at the edge of water bodies. Therefore, heterogeneity in microhabitats tends to make it more difficult to observe all individuals belonging to each species (Vitt et al. 2007).

Tropical evergreen forest showed the greatest species richness, as well as a high number of exclusive species. These species are represented with low abundance, mainly in the snakes *A. nummifer*, *Boa imperator*, *Ninia diademata* and *T. rubra*; in contrast, GA had less species richness but showed a high abundance, for example, in *H. frenatus*,

N. rhombifer, *S. variabilis* and *L. maculata* (Table 1). SCP did not contain exclusive species; however, in this environment, the species *H. amphigrammus* and *Scincella gemmingeri* occurred with high abundance (Table 1). These results are similar to other studies that compare species composition amongst environments with different vegetation structure; for example, Pianka (1989) and Urbina-Cardona et al. (2006) found that lizard species, which prefer open areas, showed higher population sizes than populations inhabiting preserved forests (Gardner et al. 2007). In our study, *S. variabilis*, *H. frenatus* and *Ctenosaura acanthura* were found in high abundance in open areas of GA. The permanence of the species in each environment is influenced by their generalist habits and use of the different microhabitat types in the modified environment. SCP showed microhabitat conditions of temperature and humidity that promote the establishment of some reptile species, such as those which occurred in this study.

With regards to the equity, this is a measure of species diversity considered in studies on structure and species composition of an environment (see Magurran and McGill 2011). This measure allowed the determination that GA differed highly from TEF and SCP in number and abundance of species. This pattern was due to a greater species number, including *inter alia*, *H. frenatus*, *S. variabilis* and *Storeria dekayi*, which are considered tolerant to those conditions found in homogeneous environments such as GA and because these species have been reported as abundant (Martín-Regalado et al. 2011).

The results of diversity and composition of communities of reptiles in each environment are supported by a taxonomic diversity analysis (a measure complementary to species diversity), where TEF and SCP were similar in this value of diversity; however, GA showed higher values (Figure 5a). These values of taxonomic diversity between TEF and SCP exhibited a high similarity in composition of species, genera and families; therefore, it suggests a similar sensitivity to the modification of the TEF and SCP environments, as was observed by Wanger et al. (2010). These authors compared the richness and diversity of amphibians and reptiles amongst environments with different degrees of disturbance and recognised that amphibians were more abundant in disturbed than conserved environments; consequently, disturbed habitats had high values of diversity. GA showed the highest value of taxonomic diversity and, in this site, *Kinosternon herrerai*, *L. maculata* and *S. variabilis* were present. These species are characterised by high displacement and tolerance to modified environments, in contrast to those species that occurred in TEF and SCP, with which it showed the highest values of beta diversity (0.97 and 0.81, respectively). These differences in species number and composition of communities of reptiles show a reduction in diversity from small portions of tropical forest to areas under agricultural management (Luja Molina 2005). Our study showed a similar pattern, in which TEF and SCP lost 72% of the reptile diversity when they are transformed to GA.

In summary, a change in species number from TEF to SCP and GA showed a pattern of species loss. From TEF to SCP, there was species loss while, from TEF to GA, there was severe loss and replacement by new, supposedly opportunistic species. TEF and SCP, however, maintained a similar diversity and species composition of reptiles, indicating that transformed environments with similar characteristics to the untrans-

formed forest contribute to the persistence of species richness. Therefore, in addition to the analysis of richness, diversity and structure of the reptile communities amongst environments, the size of the patches, edge effect and the surrounding matrix of the fragments of the untransformed forest should also be analysed in order to identify the consequences of these factors on maintenance or loss of species. The assessment of these variables (factors) will allow the recognition of more efficient spatial turnovers. Additionally, maintenance or loss of species amongst environments might change according to the availability of resources (space-food), which in turn are influenced by environmental factors, such as temperature, precipitation and humidity (Vitt and Caldwell 2009).

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